FLIGHT TEST OF IR SENSORS ON NASA 757 AT NEWPORT NEWS / WILLIAMSBURG INTERNATIONAL AIRPORT (PHF)

D. P. Chi Nguyen, RTI International, Hampton, VA

Steven D. Harrah, William R. Jones, NASA Langley Research Center, Hampton, VA

Abstract

Researchers at the National Aeronautics and Space Administration (NASA) Langley Research Center are developing a Synthetic Vision Systems (SVS) to provide pilots the safety and operational benefits of VFR-like capabilities during Instrument Meteorological Conditions (IMC). One system concept (promoted by NASA) augments the SVS concept with real-time feedback from a suite of sensors, which have been historically referred to as Enhanced Vision (EV) technologies. As part of the EV element a three-camera system that includes a CCD, short-wave IR, and long-wave IR camera has been developed to provide Infra-red (IR) imagery to enhance the SVS concept. The system was previously tested during a field deployment to Colorado's Eagle County Airport during August of 2001. On May 15, 2002, the NASA FLIR Pod was flown for the first time during dusk and night conditions at Newport News / Williamsburg International Airport (PHF). The test included three taxis, two take-offs, and eight approaches including two landings. The results from the test were significant to the continued development of the system. This paper presents the background of the system, the description of the sensors, flight test results, planned enhancements to the system, and future test plans.

Introduction

In May 1998, NASA initiated a program to support the aviation community by developing systems to improve air travel safety through the creation of the Aviation Safety Program (AvSP). The goal of this program is to contribute to the reduction of the aviation fatal accident rate by 80% over the next ten years. Because of the numerous causes and factors that contribute to the variety of accidents and incidents that occur each year, NASA has identified and is funding a wide variety of projects in order to achieve this goal. One such effort is the Synthetic Vision Systems (SVS) project that is investigating the primary, non-mechanical cause of accidents; specifically, pilot errors caused by a lack of vision or visual cues, including lack of situational awareness. Additionally, with a robust SVS, pilots will be able to conduct Visual Flight Rule (VFR) operations, even when actual visual ranges preclude them; thus, decreasing operating costs and maintaining and improving safety [1].

Synthetic Vision promises the ability to operate using Visual Flight Rules under most Instrument Meteorological Conditions. The primary technologies utilized by SVS concepts are highly accurate terrain databases and Differential GPS positioning; however, these system concepts will require some feedback from other independently monitoring systems. The Enabling Technologies (ET) element of SVS accelerates the development of fundamental technologies that are critical for SVS to eliminate controlled flight into terrain (CFIT), runway incursions (RI), and general aviation (GA) aircraft upset or loss of control in IMC [2]. NASA is developing one system concept to augment the SVS concept with real-time feedback from a suite of sensors which have been historically referred to as Enhanced Vision technologies. In response to the FY 2000 Congressional appropriations, NASA established an Enhanced Vision technology development effort within the Aviation Safety Program. This level-4 element was established to provide direct, sensor-based, feedback of the terrain and fixed/moving obstacles in support of the SVS project.

SVS Description

The operational goal for SVS is to provide operators the safety and operational benefits of VFR-like capabilities during Instrument Meteorological Conditions (IMC) [1]. The SVS concept, as originally conceived, is based upon use of the GPS data and database representations of terrain, obstacles, and high-resolution inserts of the airport layout, integrated with available Communication, Navigation, and Surveillance (CNS) information. While GPS and databases can provide the primary framework for an operational system, many in the aviation community believe that independent integrity monitors for both surveillance and navigational functions will be required to meet certification and safety requirements. The SVS program intends to use Traffic Collision Avoidance System (TCAS), Automatic Detection Surveillance - Broadcast (ADS-B), and Airport Surface Surveillance Radar (ASSR) for surveillance purposes. While these systems can provide integrity assurance to some degree, the systems rely upon cooperation and communication of information to maintain safe operations. Many in the aviation industry believe that this type of integrity assurance partially fulfills rigorous certification requirements.

Airline pilots and others in the avionics community continue to promote onboard sensors (either modified or new) as a requirement to augment the projected sensor suites including CNS and terrain databases. NASA accepted these recommendations. In response, NASA developed three specific programs including: air-to-air traffic surveillance, a runway incursion monitor, and a minimal confirmation of database registration (navigational position confirmation). All of these activities rely on in situ sensors. As part of the EV element a three-camera system that includes a CCD, short-wave IR, and long-wave IR camera has been developed to provide enhanced IR imagery to augment the SVS concept. The three-camera system supports the goal of a sensor-enhanced SVS in providing improved pilot situational awareness during all phases of flight and in all weather conditions.

EV/IR Sensor Function

SVS provides pilots with an integrated, real-time imagery utilizing existing technologies that will enable VFR-like operations in all phases of flight and during all day/night/weather conditions. EVS-derived information can be provided directly to the pilot or used for “integrity assurance” in a database-driven synthetic vision system.

At the inception of the program, several sub-products were planned for demonstration that would serve as critical functions for the system. These critical functions include air-to-air object detection (Non-Cooperative Aircraft Tracking), air-to-ground object detection (Runway Incursion Detection and CFIT-Avoidance), and ground-to-ground object detection (Runway Operations) [3]. These sub-functions integrated and built on a modified airborne Doppler radar and FLIR technologies that were studied under NASA’s High Speed Research Program (HSR). The association and blending of tracks from multiple targets and sources would ultimately evolve into a capability for Multi-Target Tracking (MTT), which with automatic detection could result in a totally automated system for object detection and subsequent mitigation of threats by the cockpit. For terrain feature extraction the Sensor Enhanced-Synthetic Vision Systems (SE-SVS) becomes a blending of non-expectation driven (DIME) information with expectation-driven information derived by sensors to provide runway confirmation and identification of missing features in real-time scenarios [3].

While the radar can fulfill many applications for transport aircraft, the use of FLIRs and low-light visible-band cameras have a role to perform and a niche that cannot otherwise be filled. On smaller aircraft (commuter, business jets, and GA) where the proposed radar technology cannot be installed, FLIR and low-light visible cameras are likely the only sensor candidates to perform all of the following functions.

Runway Incursion Monitor - Recent flight tests (NASA HSR Program) demonstrated the ability to perform autonomous, in-flight, air traffic, object detection using optical systems (visible and FLIR imagery). Extending this capability to Runway Incursion is an area of interest for EVS and will support the SV concept. These capabilities will be necessary if FLIRs are to buy their way onto commercial transports.

Situational Awareness - The primary function of these units. Whether directly shown to a pilot or as part of the synthetic paradigm, FLIR imagery can provide confirmation of terrain features, runway/taxiway locations, other aircraft, and the natural horizon in poor visibility conditions where a pilot could otherwise become disoriented and make fatal mistakes.

Night/Low-Visibility Taxi - Among the primary uses, FLIRs can provide day-like imagery that can be provided to the pilot directly or used to confirm the location of scene features. Image processing algorithms can be applied to the raw imagery to extract runway/taxiway lights, edges, and intersections as well as parked aircraft/vehicles or ground personnel.

FLIR Pod Description

This section describes the three-camera system (FLIR Pod) that has been developed for testing on the NASA 757. Engineers at RTI International have designed and integrated two forward-looking infrared (FLIR) cameras and a visible camera in an environmentally controlled and pressurized enclosure. The NASA aircraft IR system configuration is composed of a visual (CCD) camera, a short wave FLIR, and a long wave FLIR. An environmental monitoring and controlling system that includes a thermoelectric heater/cooler is incorporated inside the pressurized enclosure. Additionally, a heat sink has been added to help dissipate heat generated by the cameras. The two FLIR imaging sensors and the CCD camera are mounted in an enclosure that has been integrated into a 757 forward equipment bay access door. Figure 1 shows a side view of the mechanical layout and integration into the hatch door. This sensor location was not considered optimal from an operational perspective but was configured in this manner to provide rapid swapping of the cameras and housing with the original equipment bay access door when the aircraft was not in the FLIR test configuration.

Figure 2 shows the FLIR Pod as installed on the NASA 757. The pod is located forward of the nose gear, centered-laterally, and integrated into the forward avionics bay hatch door on the belly of the aircraft. The pod houses three cameras: a Long Wavelength IR (LWIR), a Short Wavelength IR (SWIR) camera, and a color CCD (visible band) camera as a visual reference. The electrical interfaces are routed across the pressurized enclosure through hermetically-sealed connectors.

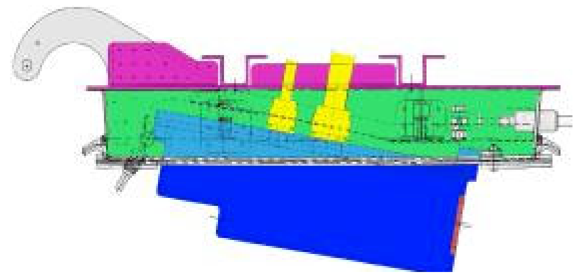

Figure 1. Mechanical Layout of FLIR Components

Figure 2. FLIR Pod Installed on NASA 757

Visible/FLIR Cameras

The cameras selected for inclusion in the FLIR Pod represented the state-of-the art IR technology at the time of design. The ultimate goal is to capture the optimal imagery from each camera and fuse them to provide a single multiband image. The visible camera used is a commercially available Bowtech BP-L3C-II CCD system covering the visible band (0.4-0.78 μm). The specifications for the Bowtech camera are listed in Table 1.

Table 1. Visible Camera Specifications

Image Sensor	1/4" CCD
CCD Elements	542 (H) x 587 (V) PAL
Horizontal Resolution	350 TVL horizontal
Sensitivity	3 lux (scene)
Signal to Noise Ratio	>46 dB (AGC off)
Composite Video Output	1.0 V peak to peak
Scanning	525 Line 60 Hz NTSC
Field of View	84° Diagonal in Air; 60° in Water
Focus	Fix 100mm ~ to infinity
Window	Acrylic
Length	100.20mm (3.9 inches) (excluding connector
Diameter	31 mm (1.2 inches)
Weight	0.266 Kg (0.6 lbs)
Temperature (Operating)	-10° ~ +40° C (-14° ~ +104° F)

The SWIR camera is another commercially available IR camera from Indigo Systems. The SWIR camera is a Merlin Near-Infrared (NIR) that is sensitive in the 0.9-1.68 μm region. At this waveband, the SWIR is optimal for detecting the peak radiance from runway lights. The Merlin-NIR is a high performance camera system, based upon the ISC9809 Focal Plane Array, using uncooled Indium Gallium Arsenide (InGaAs) detectors. The NIR camera's adjustable integration time (1 μ -16.5 ms) expands the dynamic range by four orders of magnitude (a factor of 10,000). Two gain modes provide an additional order of magnitude of dynamic range [4]. Unlike CCD cameras, Merlin NIR permits imaging well beyond the cutoff wavelength of 1100 nm in silicon. InGaAs is the best detector material available for sensing energy in the 0.9 to 1.68 μm wideband. It has high reliability (>14,000 hrs MTBF), low life cycle cost, no cryogenic cooler, no chopper, no scanner, and excellent spatial resolution. Factors that influence the Merlin selection include its size, weight, performance, and reliability. The specifications for the Merlin NIR camera are listed in Table 2.

Table 2. SWIR Camera Specifications

Detector Type	Indium Gallium Arsenide
Detector Spectral Range	0.9 — 1.68 microns
Array Format	320 H x 256 V pixels
Display Format	320 H x 240 V
Detector Size	30 x 30 microns
Operating Temperature	291 Kelvin
Startup Time	< 2 minutes at 30 C
Integration Type	Snapshot Mode
Integration Time Range	5 microsec to 16.6 millisec
Frame Rate	60, 30 or 15 frames per second * NTSC (50, 25 or 12 fps* PAL)
Size	4.0" H x 4.5" W x 8.0" L
Weight	< 3.5 lbs.
Video Output	NTSC, S-Video, Digital Video, 320 H x 256 V pixels available. 12 bits corrected or uncorrected
NEI	NEI (Low Gain) <1E10 ph/cm2/sec NEI (High Gain) <5E9 ph/cm2/sec
System Noise Level	< 2 LSB
Corrected Uniformity	< 0.1%
Operability	> 99.5% typical

The LWIR is a Lockheed Sanders LTC500 thermal imager. The LWIR senses energies in the 7-14 μm waveband. The LWIR camera can image background scenes such as runways, terrain, and obstacles at night and in other low visibility conditions. In more challenging, colder scenarios, the ambient thermal energy shifts to LWIR, representing a further advantage for uncooled sensors [5]. The LWIR-Thermal Imager is an advanced military hardware device. It has an advanced 327X245 uncooled bolometer focal plane array. The sensitivity of the LTC500 is comparable to that of many first-generation photoconductive systems, but requires neither a scanner, cryogenic cooler, or mechanical chopper. There are no moving parts during normal operation. The bolometer technology greatly reduces the size and weight of the camera and provides reliability with a MTBF greater than 14,000 hours. The specifications for the LTC500 LWIR camera are listed in Table 3.

Table 3. LWIR Camera Specifications

Spectral Response	7.5-14 µm
Available Horizontal FOV (Standard)	4.3-50.6 degrees
IFOV for 40-degree system	2.1 mr
Video Output	RS-170/NTSC, or PAL
Digital Output Options	8 and 16 bit Real Time
Array Format	327 X 245 Pixels
NETD (f/1, 30 Hz)	< 100 mK
Frame Rate	60 Hz
Size (Camera Body)	4.5 "(H) X 5.0"(W) X9.8"(L)
Weight (Camera Body)	4.8 lb
Power	4-29 V dc, <10 W
Optics	Motorized, Adjustable, Athermalized, and DFOV

System Installation on 757

Aircraft engineers and technicians installed the three-camera system on the NASA 757. The system's integrated hatch door design allowed easy installation for flight tests. Two cable assemblies provide video, communication, control, and power to the camera system. The two cables have MIL-STD connectors (D38999/26WH35SN and MS24266R22B19PN) to connect the pod to the aircraft system at receiving connectors on the aircraft bulkhead. Figure 3 shows the FLIR pod detached from the NASA 757 aircraft.

Figure 4 illustrates the relative location of the control center for the FLIR Pod at a research station at Pallet 18 on the NASA 757. The analog video signal coming from each camera is routed to Matrox Genesis frame grabber boards and through time code generators to encode UTC time before they are recorded onto SVHS tapes and displayed on monitors at Pallet 18.

Figure 3. FLIR Pod Detached

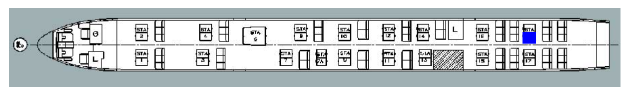

Figure 4. Pallet Layout

R-238 Test Configuration

The dusk/night flight test for the EV FLIR Pod was designated R-238. The original flight cards called for three dusk approaches and three night approaches into PHF. The approaches would consist of touch-and-go at PHF for the first five approaches with a landing and full stop on the sixth approach. Figure 5 shows the approach plate for runway 25 at PHF.

The Schedule for R-238 was as follows:

3-4pm	Maintenance Pre-flight
4-6pm	Experimental Systems Pre-flight
6-6:30pm	Principals Meeting -
730pm	Board
800pm	Take-Off
8-10pm	Conduct approaches at PHF
10pm	Land at LFI

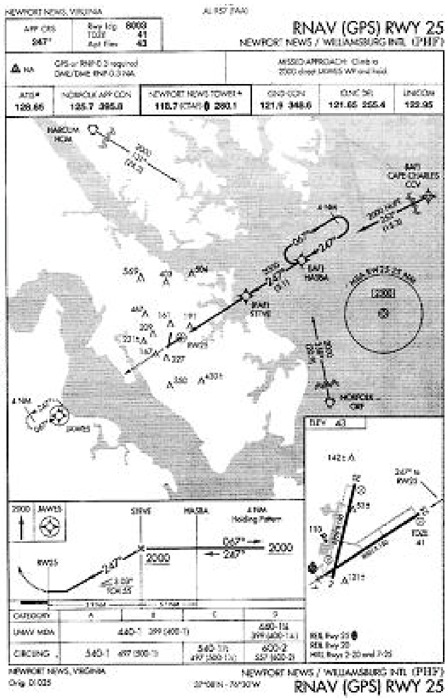

Figure 5. PHF Approach Plate for RWY 25

PHF Observations

The NASA 757 conducted a FLIR evening research flight (R-238) on Wednesday, May 15, 2002, in support of the Enhanced Vision Systems (EVS) component of the Synthetic Vision Systems Project. The flight included three dusk approaches and four night approaches at Newport News / Williamsburg International Airport (PHF). FLIR video data was recorded for all seven approaches with various runway approach lighting and camera intensity and gain settings. Data was recorded for take-offs at LFI and PHF as well as the taxis at both airports. In addition, the data for the return approach at LFI was also recorded along with the taxi back to the NASA hanger. The FLIR data collected will be very useful in supporting continued image enhancement activities.

A test of the Merlin up scan converter (RS-170 to RS-343) was performed at NASA Langley after the NASA 757 landed. NASA test pilot, Harry Verstynen, made a positive assessment of the performance of the Merlin device. The new RS-343 signal path evaluated on the ground showed significant improvements in providing a better dynamic range for contrast and brightness control of the image on the HUD. The other significant improvement afforded by RS-343 was that the runway, taxiway, and terrain features were more conformal than with the RS-170 implementation.

Overall, the data and operational experience provided confirmation of the enhancement capabilities of the LWIR and SWIR cameras for runway incursion monitor, situational awareness, and night/low-visibility taxi. Figures 6 through 36 are frames that were grabbed from the approaches into PHF. Included in the sets for each pass are images from the visible, SWIR, and LWIR, respectively. The first two approaches were made right before sunset, but the immediate observation is the scene and terrain feature enhancement from the LWIR imagery. Subsequent approaches after sunset showed even more enhancement results for the LWIR camera. For fourth and fifth approaches, the runway lights were set at different intensities (Low to High) to capture the effectiveness of the SWIR camera. On the low-level setting, the SWIR camera showed the capability to detect the runway lights better than the visible camera. The impromptu test provided confirmation of the luminance detection capability of the SWIR. The general observations presented in this paper will be updated in the presentation at the conference. More detailed description will be provided along with the presentation.

Figure 6. PHF 1st Pass Visible

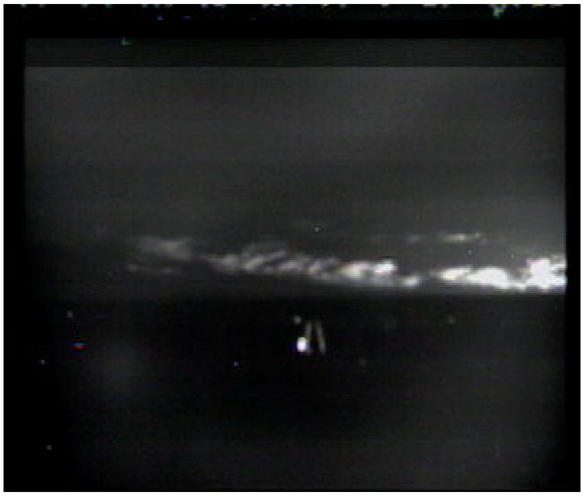

Figure 7. PHF 1st Pass SWIR

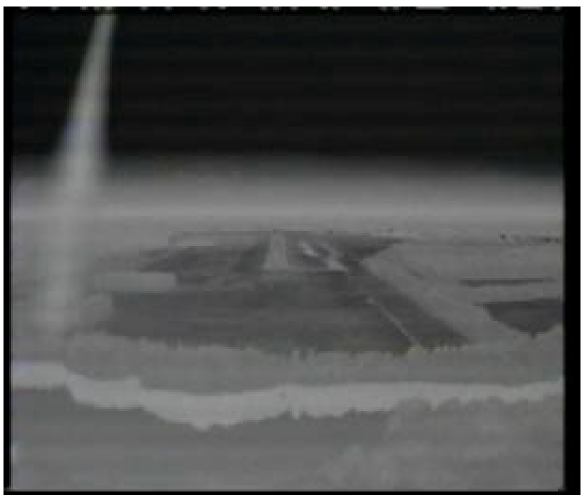

Figure 8. PHF 1st Pass LWIR

Figure 9. PHF 2nd Pass Visible

Figure 10. PHF 2nd Pass SWIR

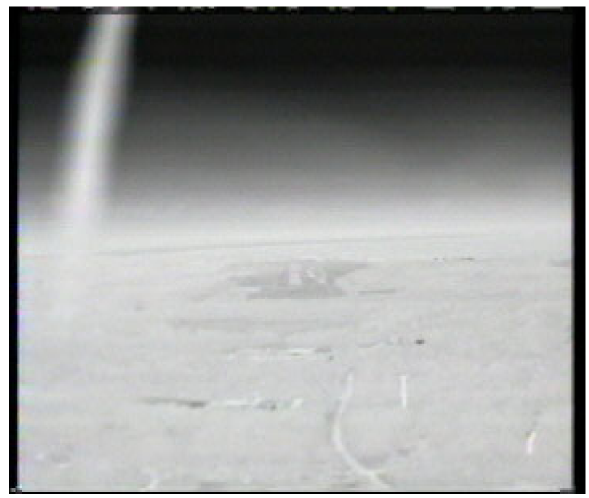

Figure 11. PHF 2nd Pass LWIR

Figure 12. PHF 3rd Pass Visible

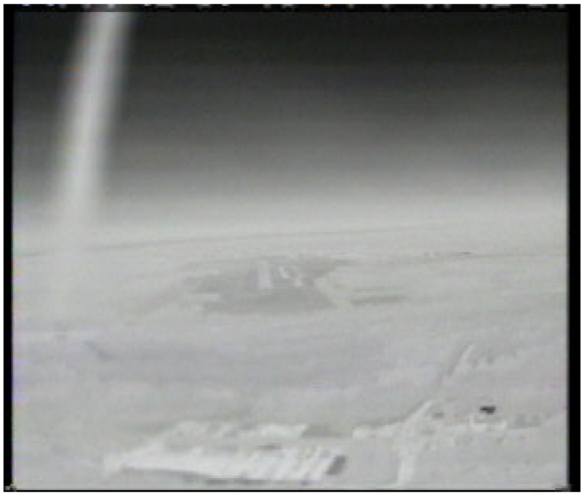

Figure 13. PHF 3rd Pass LWIR

Figure 14. PHF 4th Pass Medium Light

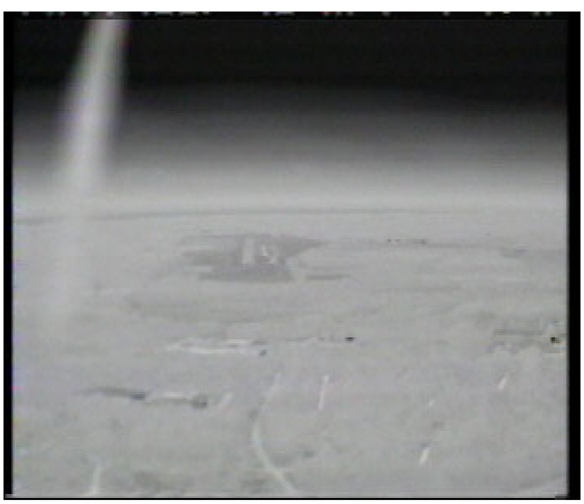

Figure 15. PHF 4th Pass LWIR

Figure 16. PHF 4th Pass HI Light

Figure 17. PHF 4th Pass HI SWIR

Figure 18. PHF 4th Pass Low Light

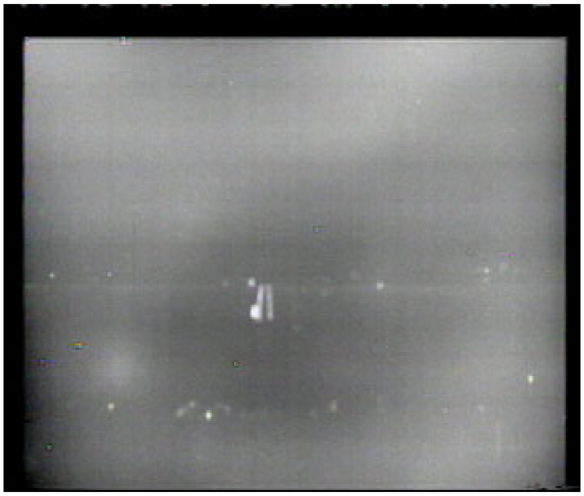

Figure 19. PHF 4th Pass Low Intensity Light SWIR

Figure 20. PHF 5th Pass Lowest Light

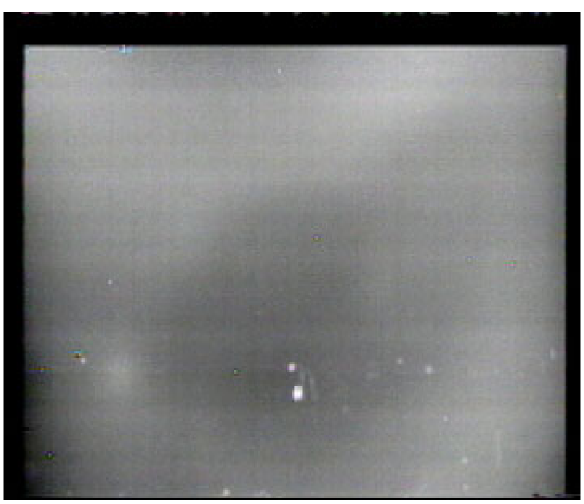

Figure 21. PHF 5th Pass Lowest Light SWIR

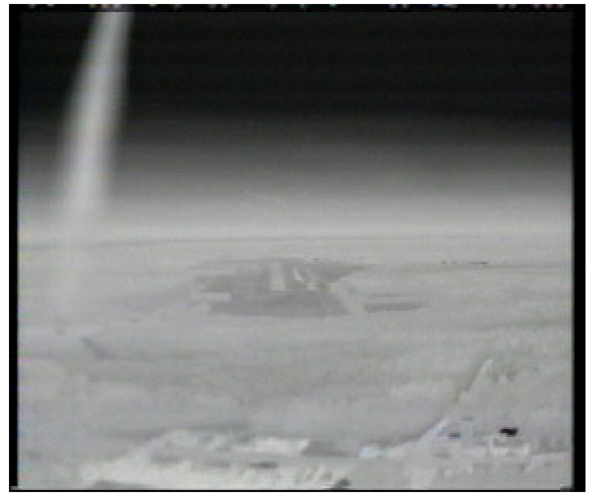

Figure 22. PHF 5th Pass LWIR

Figure 23. PHF 6th Pass Medium Light

Figure 24. PHF 6th Pass Medium Light SWIR

Figure 25. PHF 7th Pass 53 sec from threshold

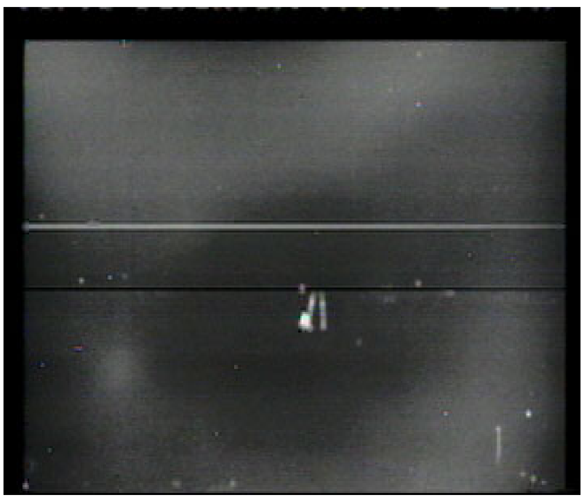

Figure 26. PHF 7th Pass 53 sec from threshold SWIR

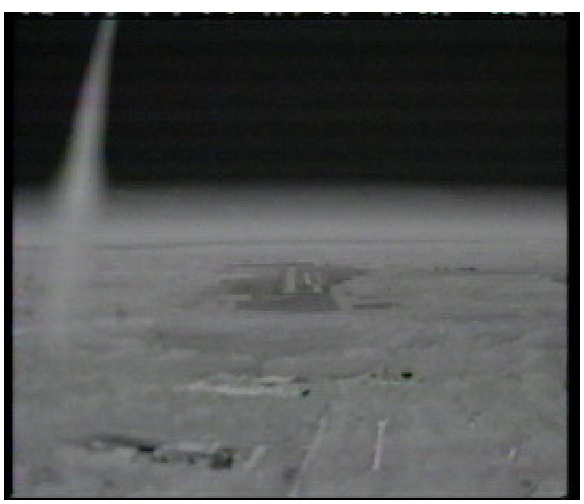

Figure 27. PHF 7th Pass 53 sec from threshold LWIR

Figure 28. PHF 7th Pass Threshold

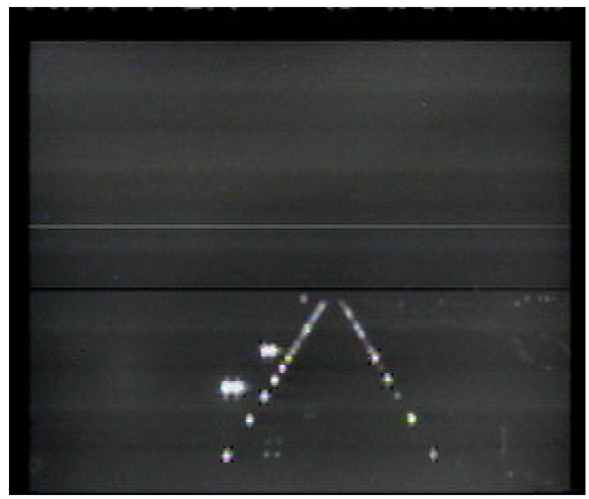

Figure 29. PHF 7th Pass Threshold SWIR

Figure 30. PHF 7th Pass Threshold LWIR

Figure 31. PHF 7th Pass Nose Down

Figure 32. PHF 7th Pass Nose Down SWIR

Figure 33. PHF 7th Pass Nose Down LWIR

Figure 34. 7th Pass Taxi

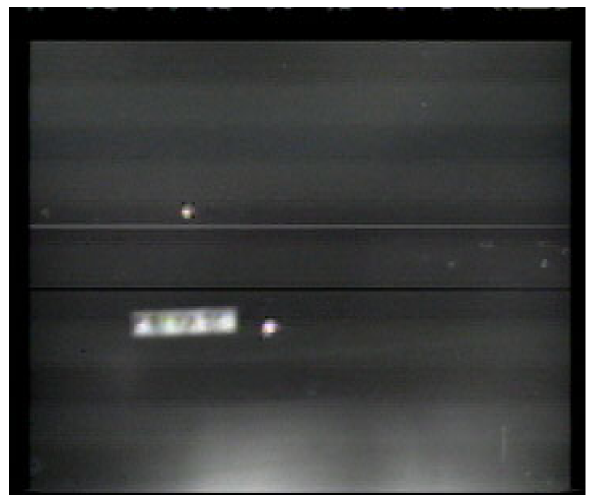

Figure 35. 7th Pass Taxi SWIR

Figure 36. 7th Pass Taxi LWIR

Planned Enhancements and Future Flight Tests

The results from the PHF will be used to continue the development and enhancement of the FLIR Pod. Specifically, image quality enhancements are being considered with the application of Retinex technologies developed at NASA Langley Research Center [6, 7, 8]. Preliminary results in image enhancements with Retinex have showed promising results.

The FLIR data collected at PHF will be very useful in supporting development and implementation of a digital video transmission system to take advantage of the parallel digital output capabilities of the SWIR and LWIR cameras. Because of the distance separating the location of the IR cameras and the digital recording system on the NASA 757, a fiber optic system has been designed for the INSITE test in 2003 [9]. For the INSITE flight tests, both analog and digital video will be recorded to support the development of real time image fusion.

Summary

The operational experience and preliminary analysis of the IR and visible imagery collected during the PHF test flight has provided significant contributions to the continued development of the hardware and software efforts of the FLIR component of the EV element. The experiences gained include operational performance of the LWIR and SWIR cameras in dusk/nighttime environment. Verification of the operational performance of the Merlin video up scan converter was important in the presentation of imagery onto the head up display (HUD).

Also, the FLIR data collected will be very useful in supporting continued image enhancement and fusion activities.

Acknowledgement

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References

[1] Baize, Dan and Cheryl Allen, "2.6 Synthetic Vision System Project Plan Version IIIe," November 28, 2001.

[2] Kudlinski, Robert A. and Dan Baize, "2.6.3 Enabling Technologies, SVS Element Plan, Version 3.0," September 21, 2001.

[3] Harrah, Steve, William Jones, Carl Erickson, and Joe White, "The NASA Approach to Realize a Sensor Enhanced-Synthetic Vision System," 27-31 October 2002, 21st Digital Avionic Systems Conference, Irvine, CA.

[4] Information obtained from company website, http://www.indigosystems.com June 2001.

[5] Kerr, Richard J. and Scott P. Way, "New Infrared and Systems Technology for Enhanced Vision Systems," 27-31 October 2002, 21st Digital Avionic Systems Conference, Irvine, CA.

[6] Z. Rahman, D. J. Jobson, and G. A. Woodell, "Retinex processing for automatic image enhancement," Human Vision and Electronic Imaging VII, SPIE Symposium on Electronic Imaging, Proc. SPIE 4662, (2002).

[7] Z. Rahman, D. J. Jobson, G. A. Woodell, and G. D. Hines, "Multi-sensor fusion and enhancement using the Retinex image enhancement algorithm," Visual Information Processing XI, Proc. SPIE 4736, (2002).

[8] B. Thompson, Z. Rahman, and S. Park, "A Multi-scale Retinex for Improved Performance In Multi-Spectral Image Classification," SPIE International Symposium on AeroSense, Visual Information Processing IX, April 2000.

[9] Kramer, Lynda, et al, "Flight Test Requirements Document Aviation Safety Program Synthetic Vision Systems (SVS) Project Initial SVS Integrated SVS Flight Technology Evaluation (InSITE) ICD Ver. 2.2," 12 July 2002, Hampton, VA.